



Behaviors of older pedestrians at crosswalks in South Korea

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ABSTRACT

This paper aims to explore three walking behaviors of older pedestrians that may increase their crash risks when crossing urban streets. Older and younger pedestrians' start-up delay in initiating a crossing and number of head turns during street crossing are observed at 30 pedestrian crossings in Seoul, South Korea, using video recorders. In addition, their estimation of the safe crossing distance to an approaching vehicle is collected in a survey. Our study shows that older pedestrians have a shorter start-up delay time than younger pedestrians, older pedestrians crossing streets turn their heads less frequently, and older pedestrians provide less reliable estimates about the distance of an approaching vehicle. Safety technologies, campaigns and environmental designs should target these behaviors to improve the safety of older pedestrians.

1. Introduction

1.1. Background and rationale

The world population is ageing (UN, 2016; MOI, 2015). South Korea's older population (65 years or older) is also growing dramatically with its share of the population increasing from 3.1% in 1970 to 12.2% in 2013 (MOI, 2015), and it is expected to grow to about 40% by 2060 (KOROAD, 2015; MOI, 2015). There are many problems associated with an ageing population (Bloom et al., 2011; Scialfa et al., 2010; Salvi et al., 2007; Christensen et al., 2009); and the loss of lives due to traffic crashes is one of them (IRTAD, 2016; KOROAD, 2015; Choi et al., 2017;). Many studies have found that older people, who are 65 years or older, have a higher fatality rate (per licensed driver or per billion km), and there is a distinctive pattern for the age distribution of fatal crashes (IRTAD, 2016; Tay, 2006, 2008, 2012a). For example, the crash rates in the United States and New Zealand show a u-shape, which has higher rates for younger (25 and below) and ageing drivers (65 and above) but a lower rate for middle-aged drivers (Evans, 2004; Fildes et al., 1994). South Korea also sees a similar curve.

From 2012 to 2014, pedestrians accounted for 38.8% of all road fatalities in Korea and 47.8% of these pedestrian deaths were people over 65 years old (KOROAD, 2015; Lee and Kim, 2011; Lee et al., 2012). There are several reasons for the higher proportion of fatality among older pedestrians. Existing literature suggests that cognitive

deficits (e.g., Oxley et al., 2001), diminished capabilities of human sensors (Lobjois and Cavallo, 2009; Oxley et al., 2001), or changes in the crossing behaviors (Lobjois and Cavallo, 2009; Oxley et al., 1997) could contribute to the increased crash rate for older pedestrians. Moreover, South Korea's local conditions that may influence older pedestrian crashes need to be examined. One important consideration of older pedestrian crashes in Korea is the location on the roadway where the crashes occurred. Based on a crash report for three years from 2012 to 2014, it was found that there were 29,969 older pedestrian crashes and 37.6% of these crashes happened at crosswalks (KOROAD, 2015). Although these crashes involve drivers and roadway factors, risky behaviors by pedestrians when crossing at crosswalks clearly need to be examined. Specifically, more research is needed to examine crosswalk fatalities involving older pedestrians to identify any factors related to crossing behaviors that may be unsafe for older pedestrians to provide useful insights to transportation engineers and road safety professionals to improve the safety of older pedestrians.

Moreover, South Korean pedestrian crashes also exhibit another behavioral feature. According to government statistics (KOROAD, 2015), the most frequent pedestrian crash types include dart-out in first half of the street (23.0%), intersection dash (19.1%), dart-out in second half of the street (23.9%), midblock dart (26.6%), walking along roadway (5.6%), and turning-vehicle crashes (5.9%). For similar crash types, however, relatively low percentages are seen in other nations. For example, in the US, the corresponding data from Stutts et al. (1996)

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Table 1
Number and Distribution of Pedestrian Crashes by Location.
Source: KOROAD (2015).

	Mid-block Crosswalk			Intersection Crosswalk			Others	Total
	Entrance	Exit	Unknown	Entrance	Exit	Unknown		
Older (65+) Pedestrians	2,202 (19.5%)	1791 (15.9%)	2866 (25.4%)	1156 (9.5%)	1074 (10.2%)	1996 (17.7%)	196 (1.7%)	11,281 (100.0%)
Younger Pedestrians	7,432 (16.9%)	8154 (18.5%)	11,807 (26.9%)	4003 (9.1%)	4008 (9.1%)	7851 (17.9%)	707 (1.6%)	43,962 (100.0%)

shows dart-out in second half of the street comprises only 10% and midblock dart comprises only 8% of the crashes. However, part of the difference may simply be due to changes in pedestrians’ attitudes and behaviors over time.

Table 1 shows where pedestrian crashes take place. It shows that relatively more crashes involving older pedestrians (65+) occur at crosswalks located in mid-blocks than those located at intersections. This finding and the reported risky behaviors of pedestrians involved in crashes call for research on older pedestrians’ decision-making process, including how they perceive the danger of approaching vehicles and how much error they make in this process. Another interesting observation is that relatively to younger pedestrians, older pedestrians tend to collide with vehicles slightly more often when they are entering the crosswalks. Hence, it may be fruitful to examine the start-up delays of older pedestrians.

1.2. Study objective and scope

Therefore, the objective of this study is to examine older pedestrians’ street crossing behaviors that may be related to their relatively higher crash risks. We study the street crossing behaviors of younger and older pedestrians by filming their crossing behaviors with video cameras at 30 selected intersections with the highest crash rates. Data on pedestrian behaviors, including start-up times and head movements, are then extracted and analyzed. We test the hypotheses that older pedestrians will have longer start-up times and fewer head movements. In addition, a pedestrian survey is conducted to gather information on pedestrian perception and decision making, including their estimates of the distance from the crosswalk to an approaching vehicle when it is first considered unsafe to cross the street. We then test the hypothesis that older pedestrians have less accurate perception of the vehicles; particularly, their estimates of the distances and the proportion of participants who would be unsuccessful in crossing the street safely. In short, this study aims to explore three possible explanations for the abnormally high older pedestrian crash rate in South Korea and provide some evidence-based recommendations to improve older pedestrian safety.

2. Methodology

From 2012 to 2014, there were a total of 10,835 older pedestrian crashes at crosswalks in South Korea and, among the major cities, the city of Seoul had the highest (2119) crosswalk crashes. Therefore, Seoul was selected as the case study area and the top 30 sites with the highest older pedestrian crosswalk crashes were chosen as the study sites. Ten of the sites were located at intersections while the remaining 20 were located at mid-blocks. Video cameras were used to capture pedestrian crossing behaviors at the 30 selected crosswalks from July 4, 2016 to July 15, 2016.

A total of 900 pedestrians were then randomly sampled and interviewed after they had successfully made the crossing at the selected sites. The sample consisted of 15 randomly selected subjects for each age group at each of the 30 study sites. For pedestrians travelling in a group or platoon, the leading person of each platoon was selected because this person would walk without interruption from other pedestrians. The self-reported age distribution of the participants is shown in

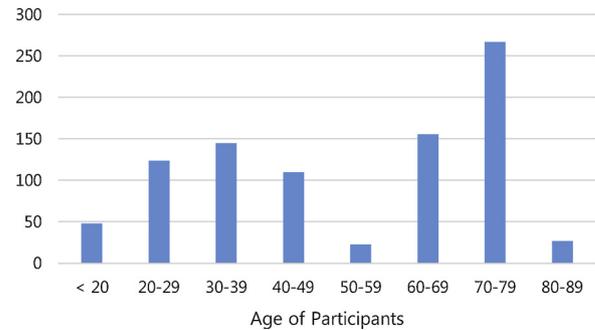


Fig. 1. Age Distribution of Participants.

Fig. 1. In this study, older pedestrians are defined as pedestrians aged 60 years or more.

2.1. Video data on pedestrian crossing behaviors

Data from the videos were then extracted in the transportation laboratory at the university. The total time spent in the crosswalk was obtained by checking the elapsed time between the times when the pedestrian entered and exited the crosswalk. However, as shown in Table 1, older pedestrians tended to collide with vehicles more often when entering the crosswalk than when exiting it. Hence, total crossing time would be a less appropriate measure of safety. Instead, we assessed the start-up delay of a pedestrian, which was defined as the amount of time covering the start of the pedestrian signal to the moment when a pedestrian entered the crosswalk. In this study, since the amount of time that elapsed in the start-up delay was very small, Eq. (1) was used to get an estimated value to check the measured values. Fig. 2 shows how the pedestrian start-up delay is estimated in this study.

$$t_s = t_t - (n+m/w)^* - t_a \tag{1}$$

- where, t_s = start-up time for pedestrians in the crosswalk
- t_t = total time spent in the cross walk
- n = number of lanes
- m = median width
- w = width of travel lane
- t_a = time required for crossing one travel lane

While crossing the street, pedestrians are continually exposed to the potential of crashes with vehicles but a pedestrian who is attentive of the surrounding traffic conditions may have a reduced crash risk. Since a pedestrian’s head turn was easily detected in the video, we decided to count the number of head turns for each pedestrian. In this study, one head turn was recorded whenever a pedestrian turned his/her head 60° or more. Fig. 3 illustrates the example of pedestrian head turns.

2.2. Pedestrian perception survey

Besides the objective and observable data on older pedestrian behaviors, some subjective and/or unobservable data on pedestrian perception is also needed to provide a better understanding of their crossing behaviors. A safe crossing involves the correct coordination between perception of the approaching vehicle and the time needed to

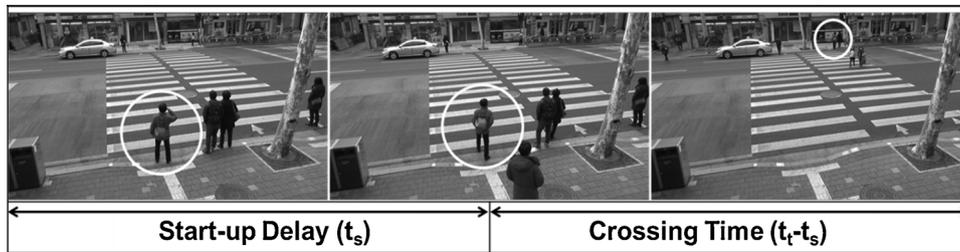


Fig. 2. Pedestrian Start-up Delay in the Crosswalk.

walk across the street. Since this process involved a reliable estimation of the distance to the approaching vehicle, we decided to check the accuracy of distance estimations by pedestrians. Fig. 4 is the concept used in this study. The participants were asked to look at an approaching vehicle and state when it was no longer safe to cross the street. They were then asked to provide their estimates of distance, in meters, between the crosswalk and the point where it was no longer safe to cross the street. This estimated distance was then compared to the actual distance computed using the video data of the vehicle and the crosswalk.

We anticipated that older pedestrians would provide less reliable estimates than younger pedestrians, eventually exposing themselves to higher crash risks. We also developed Eq. (2) to see whether a successful street crossing would be made.

$$t_v > t_a + t_s$$

$$t_v > t_t - (1 + n + m/w) * t_a \tag{2}$$

where, t_v = vehicle running time to pedestrians

t_t = total time spent in the cross walk

n = number of lanes

m = median width

w = 1 vehicle travel lane width

t_a = pedestrian crosswalk time per vehicle travel lane

t_s = time obtained in Eq. (1)

3. Results and discussion

3.1. Pedestrian start-up delay by age groups

Although it is widely believed that the start-up delay involving older pedestrians is greater than the one involving younger pedestrians (Olson and Sivak, 1986), our field study results, as shown in Table 2, show that older pedestrians have an average start-up delay that is smaller than their younger counterparts ($\bar{x}_1 = 1.58$; $s_1 = 0.48$; $\bar{x}_2 = 2.63$; $s_2 = 0.67$; $t = -21.572$; $p < 0.001$). Interestingly, this

finding is in contrast to the findings in the literature. For example, Oxley et al. (1997) found that older pedestrians took longer to leave the kerb than their younger counterparts. It is possible that the faster start time of the older pedestrians is due to automatic trust of the WALK signal, and a compensatory strategy for making up for their slower pace.

3.2. Pedestrian head turns by age groups

Our second hypothesis was that older pedestrians might turn their heads less frequently than younger pedestrians. Table 3 provides the summary of the number of head turns by age groups. Our result was consistent with the finding from existing literature about older pedestrian behaviors in the road crossing (Fildes et al., 1994; Staplin and Lyles, 1991). Our finding was also consistent with Avineri et al. (2012) who found that older pedestrians had about 12.4% fewer head movements than younger pedestrians.

Although older people might have difficulty turning their heads because of neck stiffness, they should do so more frequently because more head turns by the pedestrians while crossing streets would result in a significant reduction of pedestrian crash risk. During the subsequent video reviews, we found that many older pedestrians looked down on the crosswalk pavement most of the time or looked straight ahead to the other side of the crosswalk.

3.3. Vehicle distance estimation by age groups

Our final hypothesis was that older pedestrians had less accurate perceptions of the vehicles; particularly, their distances from the crosswalks. Table 4 is the summary of our results. Compared with younger pedestrians, older pedestrians showed a greater difference between the estimated and actual distances. Also, older pedestrians reported greater variations in their estimation of the vehicle distance, resulting in a higher standard deviation in the estimates.

Existing studies tell us that pedestrian crash risk can be explained by

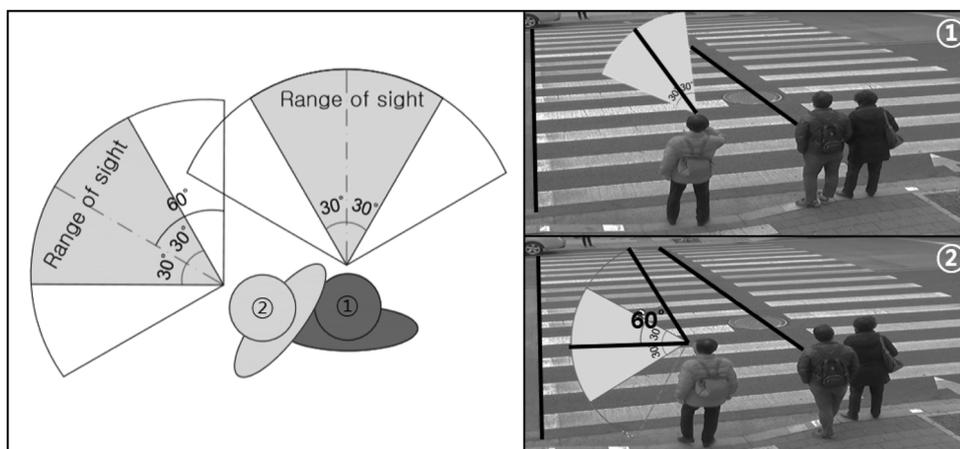


Fig. 3. Pedestrian Head Turns in the Crosswalk.

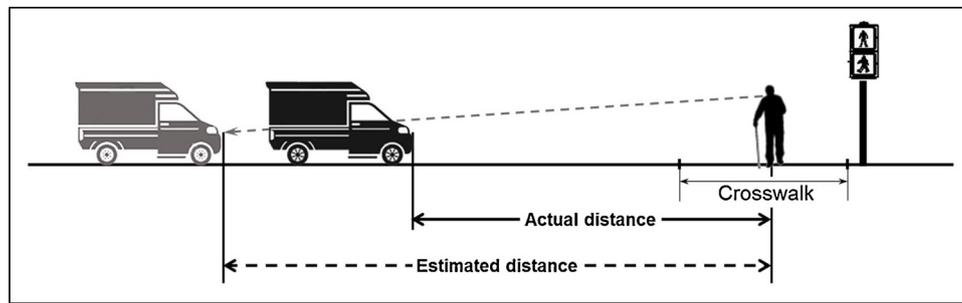


Fig. 4. Estimated Distance from Pedestrian to Approaching Vehicles.

Table 2
Pedestrian Start-up Delay by Age Groups.

	Older Pedestrians	Younger Pedestrians
Sample Size (persons)	450	450
Start-up Delay	Average (s)	1.58
	Maximum (s)	2.85
	Minimum (s)	0.94
	Standard Deviation	0.48
	t-value	-21.572
	p-value	< 0.001

Table 3
Number of Head Turns in Street Crossing by Age Groups.

	Older Pedestrians	Younger Pedestrians
Sample Size (persons)	450	450
Number of Head Turns per Crossing	Average	2.56
	Maximum	7
	Minimum	0
	Standard Deviation	1.28
	t-value	-7.69
	p-value	< 0.01

comparing the time when a pedestrian takes the first step forward to cross to the time the approaching vehicle reaches the crossing point (Oxley et al., 1997). The correct estimation of the distance of the approaching vehicle is thus critical to safe crossing by older pedestrians. We found that, on average, 3.6/15 (24.0%) of older pedestrians in our study over-estimated the distance of the approaching vehicle and would be unsuccessful in crossing safely. This finding is consistent with Taieb-

Table 4
Estimated Distance of Approaching Vehicles by Pedestrians by Age Groups.

		Older Pedestrians	Younger Pedestrians
Sample Size (person)		450	450
Pedestrians' Estimated Distance of Approaching Vehicles	Average (m)	38.6	31.7
	Maximum (m)	63.4	56.7
	Minimum (m)	20.2	15.3
	Standard Deviation	7.91	6.16
	The Estimated – The Actual Distance	Average (m)	9.6
	Maximum (m)	34.2	27.1
	Minimum (m)	-7.3	-4.1
	Standard Deviation	6.35	5.38
	t-value	2.73	
	p-value	< 0.01	
Pedestrians Who Would be Unsuccessful in Crossing Safely (number per site)	Average (Person)	3.6	1.6
	Maximum (Person)	7	4
	Minimum (Person)	0	0
	Standard Deviation	1.54	1.14
	t-value	5.63	
	p-value	< 0.01	

Maimon and Shinar (2001)'s finding that when asked to maintain "minimum safe distance", drivers maintained time headways that are considered unsafe in relation to drivers' reaction times, and that meters and car lengths yielded much lower estimates (and ones closer to the actual headways) than did seconds.

4. Conclusions

Like many developed countries, the population in South Korea is ageing and this ageing of the population is expected to have an effect on road safety. In particular, the safety of older pedestrians is a major concern because the older pedestrian safety fatality rate in South Korea is much higher than many developed countries. Therefore, more research on older pedestrians' street crossing behaviors is critical to provide some recommendations to improve their safety. This study explored three risky street crossing behaviors of older pedestrians at 30 crosswalks with high crash records. We find that older pedestrians have a shorter start-up time than younger pedestrians. Older pedestrians crossing the street turn their heads less frequently than younger pedestrians. Older pedestrians provide less reliable estimates of the distance of vehicles approaching the crosswalk.

Therefore, to improve the safety of older pedestrians, some training and education programs could be developed to improve the visual and spatial perceptions of older pedestrians, and to advise them to allow for bigger perceived gap when crossing the roads. Also, a more targeted communication campaign (Shiwakoti et al., 2018; Tay, 2016, 2012b; Tay and D'Souza, 2015) is recommended to educate older pedestrian on the need to look at both sides of the road before engaging in street crossing, and to turn their heads more frequently in order to look at both sides of the road while crossing the street. Such campaigns have been implemented in many countries, such as Australia and the United Kingdom, to educate children on safe road crossing behaviors (e.g.,

“Stop, Look, Listen” campaign).

In addition, some engineering measures could also be provided to increase the safety of older pedestrians at cross walks. One promising measure is the animated eyes display (Van Houten, 2001) which is a pair of animated LED eyes at the pedestrian signal head that scan from side to side at the start of the “walk” signal. It is an active warning system that encourages pedestrians to scan for approaching and turning vehicles when crossing intersections. It has also been shown to be effective in increasing motorists yielding behavior (van Houten and Malenfant, 2001). Another safety technology that has been shown to increase pedestrian compliance and motorist yielding behavior is the rectangular rapid flashing beacons (Moshahedi et al., 2018) could also be considered. Also, a warning system that could detect an approaching vehicle with small time-to-collision could also be developed and trialed. Moreover, safer engineering and environmental designs such as increasing the separation width and sidewalk width should also be considered (Kim et al., 2013).

Finally, this study focuses on three pedestrians crossing behaviors. Future research could examine other behaviors that may also contribute to the safety of older pedestrians, such as their knowledge of the road rules, their trust in the traffic signal and drivers obeying them, herding or safety in numbers, and distraction or inattention.

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